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Directly Modulated and ER Enhanced Hybrid III-V/SOI DFB Laser Operating up to 20 Gb/s for Extended Reach Applications in PONs

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Abstract: We demonstrate error-free performance of an MRR filtered DML on the SOI platform over 40- and 81-km of SSMF. The device operates up to 17.5 Gb/s over 81 km and 20 Gb/s over 40 km.

OCIS codes: (140.3490) Laser, distributed feedback; (250.5300) Photonic integrated circuits; (200.4650) Optical interconnects

1. Introduction

Directly modulated lasers (DMLs) are preferred solutions for next generation passive optical networks (NG-PONs) applications [1] due to their cost-effectiveness and low power consumption. However, even if high modulation speeds have been demonstrated for such lasers [2, 3], their performance is still limited by low extinction ratio (ER), frequency chirp and reduced dispersion tolerance, which forces to operate in the O-band [1] where the higher loss reduces the power budget for extended reach (up to 80 km) over standard single mode fiber (SSMF).

To overcome these DML challenges and allow operation in the C-band, different techniques have been successfully demonstrated, such as the use of passive filtering for chirp management [4] or simple ER and dispersion tolerance enhancement by either a delay interferometer [5] or by a micro-ring resonator (MRR) [6–8]. In this respect, the progress in integration of III-V materials on the silicon-on-insulator (SOI) platform has been proved to be promising for the cost-effective implementation of ER-enhanced DMLs [7]. In [7], transmission over 50-km SSMF up to 10 Gb/s has been demonstrated, showing the capability of using integrated filtered DMLs on the SOI platform for extended reach applications in PONs.

In this work, we demonstrate an all-on-silicon transmitter which can achieve transmission distances of 40 km and 81 km over SSMF and operate at up to 20 Gb/s and 17.5 Gb/s, respectively, by directly modulating a III-V/SOI hybrid DFB laser followed by a silicon MRR filter. Error-free performance (BER<10^{-9}) of an on-off keying (OOK) modulated signal with direct detection and no digital signal processing at the receiver side is demonstrated without the need for dispersion compensation or forward error correction (FEC).

2. Static characterization of the DFB laser and MRR structure

The hybrid III-V/SOI DFB laser is fabricated as in [9] and its structure is shown in Fig. 1(a). First the silicon waveguide is defined on the SOI wafer and a 50-nm-deep Bragg grating is etched with a period of Λ = 240 nm. Then the III-V material (InGaAlAs multiple quantum wells) is bonded on the SOI wafer, then processed and a taper structure is used to couple the light from the III-V material to the silicon waveguide. The optical spectra of the hybrid DFB and its small-signal frequency responses for different bias currents between 40 mA and 130 mA are shown in Fig. 1(b) and (c), respectively.

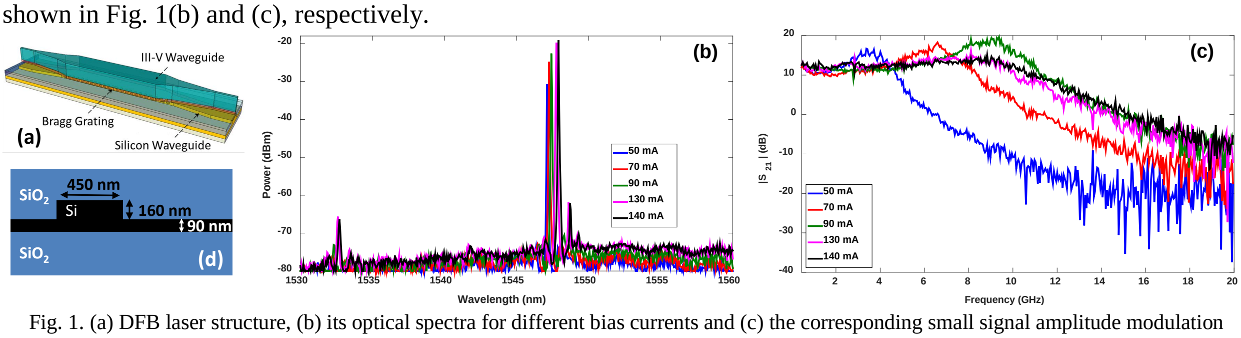

Fig. 1. (a) DFB laser structure, (b) its optical spectra for different bias currents and (c) the corresponding small signal amplitude modulation responses. (d) Cross section of the silicon waveguide employed in the MRR.

From the spectra in Fig. 1(b), a side mode suppression ratio above 40 dB is estimated, showing good single mode performance of the DFB laser. The 3-dB modulation bandwidth is extracted from the S_{21} curves in Fig. 1(c) and measured to be approximately 11 GHz for bias currents between 130 mA and 140 mA.

The MRR was fabricated on an SOI wafer with a top silicon thickness of 250 nm and a 3-µm buried silicon dioxide layer. Electron-beam lithography, inductively coupled plasma reactive ion etching and plasma- enhanced chemical vapor deposition were used to define the micro-ring structure shown in Fig. 1(d). Apodized grating couplers [10] are used to couple light in and out of the MRR and the in-to-through total insertion loss of the MRR away from resonance is 9 dB. The diameter of the MRR is 120 µm, which corresponds to a measured free-spectral range (FSR) of ~100 GHz. This parameter was designed in view of future deployment in combination with laser arrays for WDM applications (100-GHz grid). The measured Q-factor is approximately 3.8×10^4.

3. Dynamic characterization

The transmission setup is shown in Fig. 2 (a). The hybrid III-V/Si DFB laser was biased at 130.6 mA, corresponding to a 3-dB bandwidth of approximately 12 GHz, and directly modulated with a 2^7-1 non-return-to-zero (NRZ) pseudo-random binary sequence (PRBS) generated by a bit pattern generator with a peak-to-peak voltage of 2.4 V.

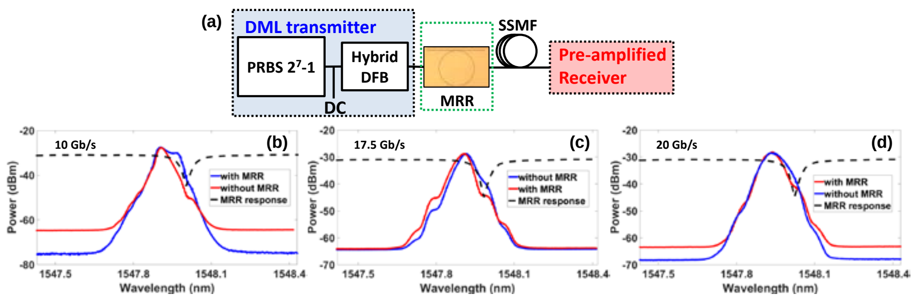

Fig. 2. (a) Experimental setup for the dynamic characterization of the chirp managed DFB laser. The spectra before and after MRR filtering for 10 Gb/s, 17.5 Gb/s and 20 Gb/s are shown in (b), (c) and (d) respectively.

The optical signal at 1547.9 nm was then filtered by the MRR for ER and dispersion tolerance enhancement. The DFB bias current was adjusted to match the resonance of the MRR, allowing the suppression of part of the low-frequency content of the optical signal spectrum, as shown in Fig. 2 (b), (c) and (d) for 10-, 17.5- and 20-Gb/s respectively. After MRR offset filtering, the signal was transmitted over SSMF and received with a standard pre-amplified receiver followed by an error analyser for bit-error-ratio (BER) measurements and a sampling oscilloscope for eye diagram recording. The results of the transmission over 81-km SSMF are shown in Fig. 3 for 10- and 17.5-Gb/s.

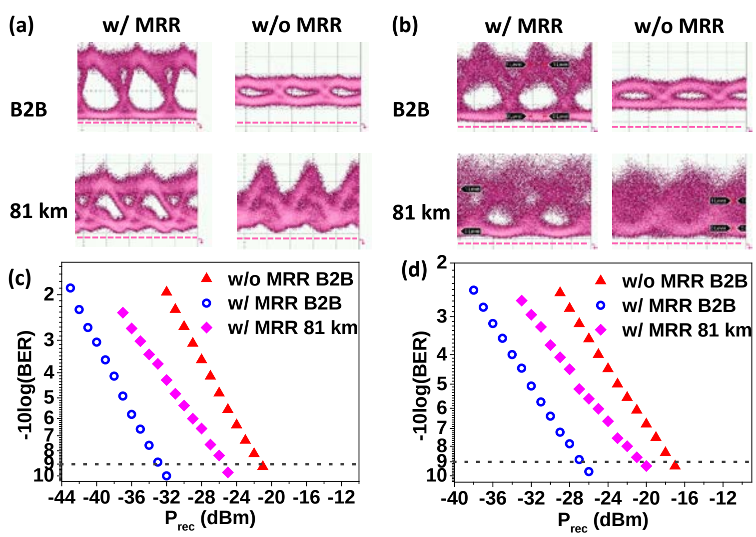

Fig. 3. Eye diagrams for back-to-back and after transmission over 81-km SSMF with and without the MRR filtering for (a) 10 Gb/s signal and (b) 17.5 Gb/s modulation. The corresponding BER curves are shown in (c) and (d) respectively.

In Fig. 3(a) and (b), the eye diagrams of the 10- and 17.5-Gb/s signals for back-to-back (B2B) and after 81 km of SSMF are shown. Considering the back-to-back scenario, the ER after filtering by the MRR is enhanced from

2.4 dB to 8.6 dB for the10 Gb/s signal and from 2.4 dB to 7.3 dB at 17.5 Gb/s. After transmission, the effects of dispersion are visible in both cases, with and without MRR. However, by using MRR filtering, the eye is still open. In fact, this ER enhancement corresponds to an improvement in dispersion tolerance and this is confirmed by the BER curves shown in Fig. 3 (c) and (d). In both cases of 10- and 17.5-Gb/s modulation, error-free performance (BER= 10^{-9}) is achieved after transmitting over 81 km SSMF when using MRR filtering. An improvement in receiver sensitivity, i.e. the received power required for a BER=10^{-9}, of approximately 4 dB compared to the back-to-back case without the use of MRR filtering is measured after 81 km transmission, while the transmission penalty compared to the back-to-back with MRR is 6 dB. No error-free performance could be achieved over 81 km without the use of the MRR and the BER values were above the measurement range of the error detector, i.e. BER>5×10^{-2}.

When increasing the modulation speed to 20 Gb/s, the SSMF length had to be reduced to 40 km in order to obtain error-free performance. The results at 20 Gb/s are shown in Fig. 4. In Fig. 4(a), the eye diagrams for back-to-back after MRR filtering show an increase of ER from 1.7 dB to 6.7 dB.

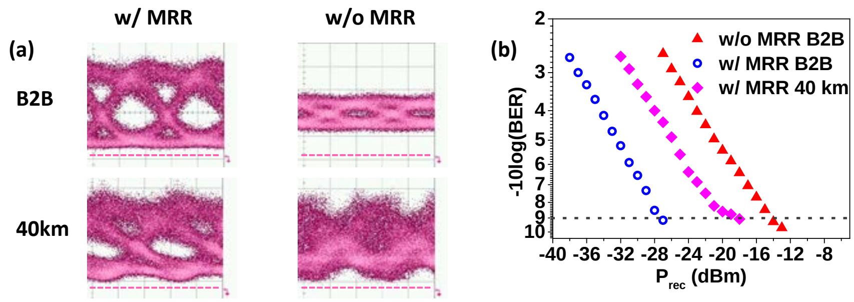

Fig. 4. The eye diagrams for B2B and after transmission over 40 km of SSMF with and without the MRR filtering are shown in (a) for 20 Gb/s signal. The corresponding BER curves are shown in (b).

As in the previous cases, this ER enhancement corresponds to an improved dispersion tolerance; in fact after transmission over 40 km of SSMF the eye diagram is still open when the MRR is used at the transmitter. The BER curves confirm this result by showing an improvement of 5 dB in receiver sensitivity after 40-km transmission compared to the back-to-back case without MRR filtering. As before, no error-free performance could be achieved at 20 Gb/s over 40 km without the use of the MRR and the BER curve could not be measured.

4. Conclusions

A hybrid III-V/SOI filtered DFB DML was demonstrated, showing an enhanced dispersion tolerance enabling transmission over 40- and 81-km SSMF. Error-free transmission over 81-km SSMF was achieved up to 17.5 Gb/s and over 40-km up to 20Gb/s, without the use of electronic equalisation techniques, FEC or dispersion compensation.

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